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Operation-management factors associated with early-postnatal mortality of US foals

Willard C. Losinger[a,*], Josie L. Traub-Dargatz[b], Rajan K. Sampath[c], Paul S. Morley[b]

[a]*USDA: APHIS: VS, CEAH, 555 South Howes Street, Fort Collins, CO 80521, USA*
[b]*College of Veterinary Medicine and Biomedical Sciences, Colorado State University, Fort Collins, CO 80523, USA*
[c]*Department of Agricultural and Resource Economics, Colorado State University, Fort Collins, CO 80523, USA*

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Abstract

Of 7320 equine foals reported born alive during 1997 on 1043 operations that had equids on 1 January 1997, and that participated in the United States National Animal Health Monitoring System (NAHMS) Equine 1998 Study, 120 foals were reported to have died (by either euthanasia or natural causes) within the first 2 days of a live birth. The weighted estimate was 1.7% mortality (standard error $=0.5$) within the first 2 days of live birth for all foals born on operations in the 28 states included in the study.

A multivariable logistic-regression model revealed that foals born in the southern region were more likely to have been reported to have died within the first 2 days of live birth than in the western region. In addition, the following operation-level factors were associated with increased odds of a foal dying within the first 2 days of live birth: not routinely testing newborn foals for adequate absorption of colostral immunoglobulins during the first 2 days of life; adding new resident equids to the operation during 1997; having non-resident equids stay on the operation for 1–30 days during 1997; never requiring an official health certificate (for operations that had non-resident equids stay on the operation for 1–30 days); using something other than straw or hay as the predominant bedding type; and feeding equids a vitamin-mineral supplement/premix with forage and/or grain. Published by Elsevier Science B.V.

Keywords: Morbidity and mortality; Horse; NAHMS; USA

* Corresponding author. Tel.: +1-970-490-7815; fax: +1-970-490-7899.
E-mail address: willard.c.losinger@usda.gov (W.C. Losinger).

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1. Introduction

The objective of equine breeders is to produce healthy foals that will grow to fulfill their aimed purpose. The neonatal period is a critical phase in an equid's life. Morley and Townsend (1997) reported that 5% of Thoroughbred foals died within 2 weeks of birth in four western-Canadian provinces. In a prospective study of foal health and management in Texas, Cohen (1994) stated that the risk of death in foals decreased with age, and was highest during the first 7 days of life. Haas et al. (1996) found that 74% of foal deaths occurred within 48 h of parturition in a large mare herd in Manitoba. The results of the National Animal Health Monitoring System (NAHMS) Equine 1998 Study of the United States Department of Agriculture (USDA) estimated that 1.7% of foals born alive either died of natural causes or were euthanized within 2 days of birth in the United States during 1997 (USDA, 1998a).

Conditions or agents that have been described as causes of foal mortality include congenital anomalies (von Matthiessen, 1993; Campbell-Beggs et al., 1995; Doige, 1996; Theoret et al., 1997), equine herpesvirus infection (Dixon et al., 1978), exposure of the pregnant mare to fescue toxicosis (Putnam et al., 1991; Cross et al., 1995), failure of colostral immunoglobulin transfer to foals (McGuire et al., 1977), septicemia (Carter and Martens, 1986), haemorrhage from the umbilicus (Haas et al., 1996), diarrhea (Cohen, 1994), pneumonia (Prescott et al., 1989), trauma (Cohen, 1994), and starvation/exposure (Haas et al., 1996).

Only a few studies have examined risk factors involved in early post-natal foal mortality. Cohen (1994) did not identify factors that were significantly associated with foal mortality-possibly because the low number of deaths observed in his study limited the power. Haas et al. (1996) found that failure of passive transfer, poor mothering ability, dystocia, low birth weight, lack of rainfall and low environmental temperatures were associated with foal death on a pregnant-mare operation in Manitoba. However, their study population was atypical of United States equine populations in that assistance to foals was minimal and foal mortality was quite high (22% before reaching 10 days of age) (Haas et al., 1996).

The purpose of this investigation was to identify management and other operation-level factors that were associated with foal death within 2 days of live birth in the United States during 1997, based on data from the NAHMS Equine 1998 Study.

2. Materials and methods

2.1. Source of data

Data used in this study were gathered from participants in the NAHMS Equine 1998 Study. The USDA's National Agricultural Statistics Service (NASS) chose participants both from lists of operations with large numbers of equids, and from operations with equids within randomly selected land areas (USDA, 1998a).

The development of the lists took place during the summer and fall of 1997, and concentrated on including operations such as boarding stables, riding and training facilities, race tracks, and other service providers. There are few of these types of operations, and few were expected to be included in the sample of land areas. During the January 1998, Equine Survey (which took place from 1 January through 15 January 1998), the NASS contacted all operators on the lists and asked their equine inventory on 1 January 1998.

The stratification of the NASS area frame (from which land areas, called ''segments'', were selected using a computer program that applied simple random sampling without replacement) was based on land use (i.e. intensively cultivated land, range land, urban land areas, and land in cities). The segments were approximately the same size within each stratum, but varied in size between strata. For example, in strata characterized by intensive cultivation or crop production, the segment size was 2.6 km^2 while in some mixed-urban strata, the segment size was 0.6 km^2. Because equids are more common near urban and suburban areas than other livestock, a higher proportion of segments from urban land areas were included in this survey than in other livestock surveys.

For each segment selected, maps and photographs were prepared. The segment was sub-divided into smaller land areas (called ''tracts''), each associated with an operator (i.e. the person responsible for day-to-day decisions). The tract operator's name was very important to avoid duplication with the lists. During the NASS Area Survey which took place in December 1997, enumerators contacted tract operators, and gathered information on the total land area operated (including areas operated outside of the tract) and the number of equids expected to be on hand on 1 January 1998.

For the NAHMS Equine 1998 Study, NASS selected a stratified random sample of respondents to the December 1997 Area Survey (who expected to have one or more equids on hand on 1 January 1998), and to the January 1998 Equine Survey (who had one or more equids on hand on 1 January 1998), from the list and area frame (USDA, 1998a). If an operation appeared on both the list and the area frame, it was represented solely from the list frame. Sample selection was performed for the list frame and the area frame separately, using a computer program that applied stratified simple random sampling without replacement. Stratum descriptions are given in Table 1. For the area frame, strata were based on both the number of equids that the operation reported, and on the expanded (i.e. weighted) number of equids which the operation represented. Sampling intervals (within strata) ranged from 1:1 to approximately 1:20, and varied from state to state. Sampling intervals for operations with larger expanded numbers of equids were smaller in order to limit the subsequent expansion factors for the Equine 1998 Study. A total of 4311 operations were selected (USDA, 1998a).

From 16 March through 10 April 1998, about 200 NASS enumerators visited operations in 28 states that had been selected for the NAHMS Equine 1998 Study to gather equine inventory data and, on non-racetrack operations, the NASS enumerators administered a questionnaire that covered topics on equine movement, housing and manure management, nutrition, health management and health events (USDA, 1998a). Respondents were asked the number of foals of any type (horse, miniature horse, pony, mule, donkey/burro, and other domestic equids) that were born alive during 1997, specific questions about the care of neonatal foals, and the number of foals that died (including euthanasia) within 2 days of live birth.

Table 1
Stratum descriptions for the National Animal Health Monitoring System's Equine 1998 Study[a]

List frame	
Stratum	Description
1	1–2 equids reported
2	3–4 equids reported
3	5–19 equids reported
4	20–39 equids reported
5	40–99 equids reported
6	$\geq$100 equids reported
Area frame	
Stratum description	Approximate sampling interval
1–2 equids reported, <200 expanded	1:1–1:20 (most $\leq$1:10)
1–2 equids reported, 200–999 expanded	1:1–1:4 (most $\leq$1:3)
1–2 equids reported, $\geq$1000 expanded	1:1
$\geq$3 equids reported, <200 expanded	1:1–1:10 (most $\leq$1:5)
$\geq$3 equids reported, 200–999 expanded	1:1–1:3 (most $\leq$1:2)
$\geq$3 equids reported, $\geq$1000 expanded	1:1

[a] For the list frame, sampling strata were based on the number of equids reported during the January 1998 Equine Survey. For the area frame, sampling strata were based on both the actual number of equids reported during the December 1997 National Agricultural Statistics Service Area Survey, and the expanded (or weighted) number of equids that the operation represented. Actual sampling intervals varied by state.

The data were weighted to permit inferences to be drawn to all operations with $\geq$1 equid on 1 January 1998 in the 28 states included in the study (USDA, 1998a). Initially, the weights were the inverse of the probability of selection. The weights were adjusted for subsequent phases of selection and nonresponse. For the data from the NAHMS Equine 1998 Study interview (16 March through 10 April 1998), weights were adjusted by multiplying the weight of each respondent by the ratio of the sum of weights of respondents to the sum of weights of eligible non-respondents within post-strata based on region and size of operation.

The distribution of the adjusted respondent weights were examined. Two weights exceeding 4550 were truncated to a maximum of 4550, and their excess weight redistributed equally among the respondents within their poststrata, following the method of Cox and Cohen (1985).

A data file was subsequently created with one observation for each foal reported to have been born alive during 1997.

2.2. Analysis of early post-natal foal mortality

Analysis were restricted to operations with $\geq$1 foals (including horses, miniature horses, ponies, mules, donkeys/burros, and other domestic equids) born alive during 1997. SUDAAN, a computer program designed specifically for the analysis of data from sample surveys and for the analysis of clustered data (Shah et al., 1996) was used to compute national estimates of the percent of foals that died within 2 days of a live birth by variables that were selected from the NASS questionnaire, and that were hypothesized to influence foal mortality. The chi-square test provided by SUDAAN served to screen variables for possible inclusion in a multivariable model. Variables with $P \leq 0.25$ were deemed eligible for inclusion in the model. Spearman rank correlations were computed, using the CORR procedure of statistical analysis systems (SAS) 1990 to examine relationships between screened variables at the operation level.

A limitation of using SUDAAN to build a logistic-regression model is that although log-likelihood statistics are adjusted for the sample weights, these statistics are not adjusted for clustering and stratification (Shah et al., 1996). Thus, one cannot statistically compare models by evaluating the ratio of the log-likelihood statistics. Therefore, procedures were used that were similar to those previously developed (Losinger and Heinrichs, 1997) for using SUDAAN to construct a multivariable logistic-regression model. Briefly, region and herd size (as measured by the number of equids that were resident on the operation on 1 August 1997) were forced into the model to make certain that other independent variables did not enter the model merely because of regional and herd-size differences in management. A forward-stepwise selection procedure (with a threshold of $P \leq 0.05$ based on Wald's F test) was used to add other variables to the model.

The expected cost of testing versus not testing foals for adequate absorption of colostral immunoglobulins within the first 2 days of live birth was compared for varying hypothetical values of foals. Probabilities of a foal dying were computed from the final logistic-regression model by setting other model variables to their weighted mean values. The analysis assumed that the cost for the test for adequate absorption of colostral immunoglobulins and the hypothetical value of the newborn foal that died within 2 days of a live birth were the only costs incurred. The test for adequate absorption of colostral immunoglobulins was assumed to cost US\$ 20. Therefore, the expected cost ($\hat{C}$) of testing for adequate absorption of colostral immunoglobulins was computed thus

$$\hat{C} = (V + 20) \times P_1 + 20 \times (1 - P_1)$$

where V represents the hypothetical value of the newborn foal and P_1 the probability of a foal dying within 2 days of a live birth on an operation that tested for adequate colostral absorption of immunoglobulin. For operations that did not test for adequate absorption of colostral immunoglobulins, the expected cost was simply $V \times P_2$, where P_2 represents the probability of a foal dying within 2 days of a live birth on an operation that did not test for adequate colostral absorption of immunoglobulin. For comparison, values ranging to US\$ 10,000 were used for the hypothetical value of a newborn foal.

3. Results

Of 4311 operations initially selected for the NAHMS Equine 1998 Study, 163 were race tracks (from which inventory data alone were collected), 37 were out of scope (such as prison and research farms), 787 refused to participate, 354 were inaccessible, 199 indicated no equids on hand on 1 January 1998, 13 indicated no resident equids on 1 January 1998, and 2758 completed the NASS questionnaire (USDA, 1998a). Of the operations that both participated in the NAHMS Equine 1998 Study and had resident

Table 2
Foal mortality within the first 2 days of a live birth (for operations that had births of live foals in 1997)[a]

Region[b]	Actual sample size		Weighted mean percent of foals born alive that died within the first 2 days per operation		Weighed percent of foals that died within the first 2 days of live birth	
	Operations with $\geq$1 live-foal births in 1997	Live-foal births	Mean	S.E.	Percent	S.E.
Southern	429	3145	3.0	1.2	2.2	0.7
Northeast	135	1279	1.3	0.9	1.6	0.9
Central	247	1338	0.7	0.4	1.2	0.6
Western	232	1558	0.5	0.4	1.1	0.5

[a] Means and percents were weighted (by the inverses of the sampling proportions and non-response) to represent all operations with live-foal births during 1997 in the 28 US states included in the study.

[b] States included in each region were as follows: Southern: Alabama, Florida, Georgia, Kentucky, Louisiana, Maryland, Oklahoma, Tennesse, Texas and Virginia. Northeast: New Jersey, New York, Ohio and Pennsylvania. Central: Illinois, Indiana, Kansas, Michigan, Minnesota, Missouri and Wisconsin. Western: California, Colorado, Montana, New Mexico, Oregon, Washington and Wyoming.

equids on 1 January 1998, 1043 reported the birth of at least one live foal during 1997. Of the reported 7320 foals born alive during 1997, 120 were reportedly euthanized or died within the first 2 days of life. For operations that had a foal born in 1997, and the number of reported deaths within the first 2 days of live birth ranged from 0 to 4 per operation (and from 0 to 100% of live births on a given operation).

Table 2 summarizes foal mortality (within the first 2 days of live birth) at the operation level and at the foal level by region. The estimates and standard errors were generated using SUDAAN to refer to all foals born on operations that had one or more equids resident on 1 January 1998 in the states included in the study. The sample weights used ranged from 1.0 to 3526.9.

For operations with at least one live-foal birth during 1997, the number of resident equids on 1 August 1997 ranged from 0 to 503 with a sample median of 20 and first and third quartiles of 10 and 43, respectively. The weighted estimate of the mean number of resident equids on 1 August 1997 (for operations with at least one live-foal birth during 1997 in the states included in the study) was 11.8.

Table 3 lists percent mortality by the questionnaire variables considered. The final multivariable logistic-regression model appears in Table 4. Foals born in the southern region were more likely to have been reported to have died within the first 2 days of a live birth than in the western region. Foals born on operations where foals were not routinely tested for adequate absorption of colostral immunoglobulins within the first 2 days of birth were more likely to die within the first 2 days of live birth than foals born on other operations. Adding new resident equids to the operation during 1997, and permitting non-resident equids to stay on the operation for <30 days were associated with an increased odds of a newborn foal dying within the first 2 days of a live birth. For operations that

Table 3
The number of US operations (and live-foal births on these operations) that reported at least one live-foal birth during 1997[a]

	Actual sample size		Weighted mortality within 2 days	
	Operations	Live-foal births	Percent	S.E.
Model variables				
1. Foals routinely tested for adequate absorption of colostral immunoglobulins during first 2 days of life				
Yes	390	4135	0.7	0.3
No	653	3185	2.0	0.5
2. Any non-resident equid came to the operation and stayed for <30 consecutive days during 1997				
Yes	421	4314	1.8	0.5
No	622	3006	1.7	0.5
3. Frequency of requiring a health certificate when non-resident equids stayed on the operation for <30 consecutive days during 1997				
Always/sometimes	220	2971	0.9	0.4
Never	201	1343	2.6	0.9
No visiting non-residents	622	3006	1.7	0.5
4. Any new resident equids added to the operation during 1997				
Yes	587	5184	3.0	0.8
No	452	2128	0.7	0.3
5. Predominant bedding type for equids was straw or hay during 1997				
Yes	294	2915	0.7	0.3
No	638	4028	2.6	0.7
6. Vitamin-mineral supplement/premix was fed to one or more equids with forage/grain				
Yes	617	4683	2.1	0.6
No	423	2617	1.1	0.4
Other variables with $P < 0.25$ (and considered in multivariable model)				
A. Primary use of equids was racing				
Yes	81	777	0.6	0.4
No	962	6543	1.8	0.4
B. Frequency of requiring a health certificate when new resident equids were added during 1997				
Always/sometimes	383	3955	2.6	1.0
Never	204	1229	3.7	1.4
No new residents	452	2128	0.7	0.3
C. Frequency of requiring a veterinary examination when new resident equids were added during 1997				
Always/sometimes	312	3262	3.0	1.2
Never	275	1922	3.0	1.2
No new residents	452	2128	0.7	0.3
D. Frequency of requiring any vaccination within past year when new resident equids were added during 1997				
Always/sometimes	441	4247	3.4	1.0
Never	146	937	2.3	1.2
No new residents	452	2128	0.7	0.3
E. Frequency of requiring deworming within past year when new resident equids were added during 1997				
Always/sometimes	438	4260	3.1	0.9
Never	149	924	2.9	1.4
No new residents	452	2128	0.7	0.3

Table 3 (*Continued*)

	Actual sample size		Weighted mortality within 2 days	
	Operations	Live-foal births	Percent	S.E.
F. Routine quarantine of new resident equids				
Routinely quarantined	280	3052	2.8	1.2
Not routinely quarantined	307	2132	3.3	1.1
No new residents	452	2128	0.7	0.3
G. Predominant bedding type used for equids during 1997 was wood shavings, chips or sawdust				
Yes	620	3944	2.6	0.7
No	312	2999	0.9	0.3
H. Any equid was fed baled alfalfa hay for ≥3 months in 1997				
Yes	496	4616	2.6	0.6
No	546	2700	1.1	0.5
I. Any equid was fed baled grass and alfalfa mixed hay for ≥3 months during 1997				
Yes	544	4125	1.0	0.3
No	497	3186	2.3	0.6
J. Any equid was fed baled forage other than grass or alfalfa for ≥3 months during 1997				
Yes	167	981	0.2	0.1
No	875	6335	2.0	0.4
K. Number of times per day equids were typically fed dried forage/hay				
Less than once	47	301	0.2	0.2
Once or twice	793	5475	1.6	0.5
Three or more/continuous access	196	1511	2.6	1.1
L. Protein-vitamin-mineral supplement/premix fed with forage/grain				
Yes	393	3023	1.2	0.4
No	647	4277	2.1	0.6
M. Vitamin supplement/premix fed with forage/grain				
Yes	268	2398	2.7	0.9
No	773	4917	1.4	0.4
N. Herbal supplements fed with forage/grain				
Yes	115	824	0.4	0.3
No	925	6476	1.8	0.4
O. Predominant source of drinking water for equids during 1997 was a municipal water supply				
Yes	237	1879	1.1	0.5
No	806	5441	1.9	0.5
Variables with $P > 0.25$ (and no longer considered)				
Routine foaling location was pasture				
Yes	312	1325	1.8	0.8
No	731	5995	1.7	0.4
Routine foaling location was designated foaling stall				
Yes	626	5399	1.7	0.4
No	417	1921	1.8	0.7
Routine foaling location was pasture or designated foaling stall				
Yes	938	6724	1.7	0.4
No	105	596	1.6	1.4

Table 3 (*Continued*)

	Actual sample size		Weighted mortality within 2 days	
	Operations	Live-foal births	Percent	S.E.
Routine foaling location was stall other than designated foaling stall				
Yes	63	322	3.5	3.2
No	980	6998	1.6	0.4
Foals routinely examined by a veterinarian during first 2 days of life				
Yes	499	3906	1.3	0.5
No	544	3414	1.9	0.5
Foal navels routinely dipped with antiseptic during first 2 days of life				
Yes	882	6720	1.5	0.4
No	160	598	2.7	1.4
Foals routinely given an enema during first 2 days of life				
Yes	559	4985	1.9	0.5
No	484	2335	1.6	0.6
Primary use of equids on operation was pleasure				
Yes	253	557	1.5	0.8
No	790	6763	1.8	0.5
Primary use of equids on operation was showing/competition (not betting)				
Yes	214	867	3.5	1.8
No	829	6453	1.5	0.4
Primary use of equids on operation was breeding				
Yes	333	4416	1.3	0.4
No	710	2904	1.9	0.6
Primary use of equids on operation was farm or ranch work				
Yes	96	344	3.0	1.8
No	947	6976	1.5	0.3
Any Thoroughbred horses (whether resident or not) on hand on 1 January 1998				
Yes	375	3494	2.0	0.6
No	668	3826	1.6	0.5
Any Quarter Horses (whether resident or not) on hand on 1 January 1998				
Yes	641	4069	1.8	0.5
No	402	3251	1.7	0.5
Any other breeds of registered horses on hand on 1 January 1998				
Yes	121	631	1.9	1.2
No	922	6689	1.7	0.4
Any resident miniature horses on 1 January 1998				
Yes	117	757	1.4	1.0
No	926	6563	1.7	0.4
Any resident ponies on 1 January 1998				
Yes	239	1338	1.9	1.0
No	804	5982	1.7	0.4
Any resident mules on 1 January 1998				
Yes	67	398	1.1	0.7
No	976	6922	1.8	0.4

Table 3 (*Continued*)

	Actual sample size		Weighted mortality within 2 days	
	Operations	Live-foal births	Percent	S.E.
Any resident donkeys or burros on 1 January 1998				
Yes	98	751	1.2	0.6
No	976	6569	1.7	0.4
Frequency of removing manure/waste bedding from equine stalls on operation				
Daily or more frequently	657	5761	1.7	0.4
Less than daily	276	1174	1.9	0.9
No stalls	104	367	1.3	0.7
Grain/concentrate was stored in rodent-proof containers				
Yes	749	4645	1.8	0.4
No	274	2606	1.5	1.0
Gender of person with primary responsibility for health care decisions for the majority of resident equids				
Male	585	4847	1.5	0.5
Female	458	2473	2.1	0.7
Gender of person with primary responsibility for health care implementation for the majority of resident equids				
Male	586	4902	1.5	0.5
Female	457	2418	2.1	0.6
Any vaccine administered to resident equids during 1997				
Yes	932	6930	1.8	0.5
No	111	390	1.3	0.6

[a] The latter was weighted by the inverses of the sampling proportion and non-response.

allowed non-resident equids to remain <30 days in 1997, mortality within the first 2 days of a live birth was higher when the operation did not require all visiting non-resident equids to have an official health certificate. Using straw or hay as the predominant bedding type was associated with a reduced odds of a foal dying within the first 2 days of a live birth. Giving equids a vitamin-mineral supplement/premix with forage and/or grain was associated with increased risk of a foal dying within the first 2 days of a live birth.

Table 5 lists Spearman rank-correlation coefficients between model variables and variables that were screened but not included in the final logistic-regression model.

Fig. 1 shows the expected cost of testing and not testing foals for adequate absorption of colostral immunoglobulins during the first 2 days of life as a function of the hypothetical value of the newborn foal with all other variables placed at their weighted sample mean values. The analysis shows that, for foals worth >≈US$ 1100, the expected cost of not testing for adequate absorption of colostral immunoglobulins was higher than the expected cost of testing for adequate absorption of colostral immunoglobulins (assuming that the only costs were US$ 20 for the test plus the hypothetical value of a foal that died within 2 days of a live birth).

Table 4
Logistic regression of a foal dying within 2 days of live birth (6915 live-foal births on 925 US operations that provided data for all model variables)

Variable	Operations	Live-foal births	Coefficient	S.E.	*P*	Odds ratio	95% confidence interval
Intercept	925	6915	−6.65	0.84	<0.01	–	–
Number of resident equids on 1 August 1997 (forced into model)							
	925	6915	0.00	0.01	0.97	–	–
Region (forced into model)							
Southern	379	2977	1.70	0.66	0.01	5.46	1.49–20.04
Northeast	131	1253	1.20	0.82	0.14	3.32	0.66–16.70
Central	242	1301	1.17	0.76	0.13	3.22	0.72–14.44
Western	173	1384	0.00	0.00	–	1.00	–
Foals were routinely tested for adequate absorption of colostral immunoglobulins during first 2 days of life							
Yes	380	4124	−1.32	0.66	0.05	0.27	0.07–0.98
No	545	2791	0.00	0.00	–	1.00	–
Any new resident equids were added to the operation during 1997							
Yes	546	5000	1.59	0.51	<0.01	4.91	1.79–13.49
No	379	1915	0.00	0.00	–	1.00	–
Any non-resident equids came to the operation and stayed for <30 days during 1997							
Yes	390	4183	1.04	0.53	0.05	2.84	1.00–8.07
No	535	2732	0.00	0.00	–	1.00	–
Frequency of requiring an official health certificate when non-resident equids came to the operation and stayed for <30 days during 1997							
Always/sometimes	211	2936	−1.77	0.65	0.01	0.17	0.05–0.61
Never	179	1247	0.00	0.00	–	1.00	–
No visitors	535	2732	0.00	0.00	–	1.00	–
Predominant bedding type for equids was straw or hay during 1997							
Yes	292	2896	−1.01	0.44	0.02	0.36	0.15–0.87
No	633	4019	0.00	0.00	–	1.00	–
Vitamin-mineral supplement/premix was fed to one or more equids with forage and/or grain							
Yes	577	4556	0.90	0.44	0.04	2.46	1.04–5.84
No	348	2359	0.00	0.00	–	1	–

Table 5
Spearman rank-correlation coefficients (unadjusted for the study design) between final-model variables and screened variables that were not included in the final model[a]

Screened variable not in final model	Model variable					
	1 (colostrum)	2 (visitor)	3 (certificate)	4 (new)	5 (bedding)	6 (vitamin)
A[a]	0.08	−0.08	−0.05	−0.05	0.09	0.06
B	0.20	0.93	0.15	0.20	−0.17	0.14
C	0.18	0.92	0.15	0.18	−0.16	0.12
D	0.22	0.94	0.16	0.19	−0.18	0.13
E	0.21	0.94	0.16	0.19	−0.17	0.13
F	0.16	0.92	0.17	0.19	−0.11	0.13
G	0.11	0.17	0.13	0.14	−0.96	0.12
H	0.16	0.09	0.12	0.13	−0.08	0.10
I	0.09	0.10	0.05	0.06	0.10	0.03
J	0.07	0.06	0.02	0.01	−0.04	0.04
K	−0.05	−0.06	−0.02	−0.02	−0.06	−0.11
L	0.15	0.09	0.06	0.06	−0.11	0.16
M	0.17	0.10	0.13	0.14	−0.10	0.30
N	0.18	0.11	0.09	0.09	−0.10	0.19
O	0.00	0.25	0.96	0.65	0.03	0.04

[a] See Table 2 for variables corresponding to the letters and numbers.

4. Discussion

Data used in this study were from the first NAHMS national study of equine health. The NAHMS Equine 1998 Study was designed to permit inferences to be drawn to the total population of equids in 28 states that accounted for about 78% of the farms with horses and ponies (and 78% of the horses and ponies on farms) based on the 1992 Census of Agriculture (USDA, 1998a). Because the 1992 Census of Agriculture did not include operations with <US$ 1000 of sales of agricultural products during the year and less than five horses, the total population of equids in these states was not known at the time that the study was designed. However, the 1992 Census of Agriculture represented the most-reliable state-level estimates of equine numbers at the time of the design of the NAHMS Equine 1998 Study.

Participants in the National Swine Survey (USDA, 1992) and the National Dairy Heifer Evaluation Project (Heinrichs et al., 1994) (which were the first two NAHMS national studies) were selected from both list frames and area frames. The area frames served to adjust estimates for incompleteness of the lists (including recent producer transition in and out of business) (Heinrichs et al., 1994). With reduced budgets, subsequent NAHMS national studies relied solely upon sampling from NASS lists of agricultural producers, and did not make use of area frames (Losinger et al., 1997). For the NAHMS Equine 1998 Study, it was possible to produce lists of operations with large numbers of equids (such as boarding stables, riding and training facilities, race tracks and other service providers). However, it would have been very difficult and costly to produce lists of all premises with $\geq$1 equids in the states included in the study. Therefore, area-frame

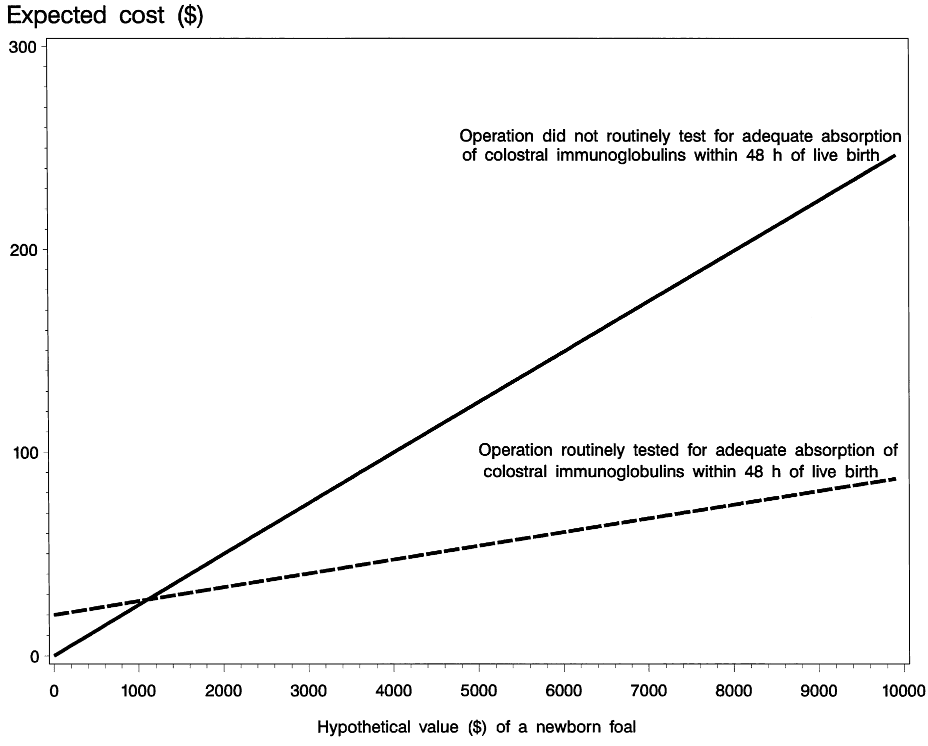

Fig. 1. Expected cost of a foal dying within 2 days of a live birth. (The only cost incurred is assumed to be US$ 20 for the test for adequate absorption of colostral immuglobulins). The probability of dying was computed from the logistic-regression model by placing the values of other variables at their weighted sample-mean values (1998, USA).

sampling (in addition to sampling from the lists) was absolutely essential for the Equine 1998 Study to be successful.

The Equine 1998 Study had multiple objectives. Participants who had three or more horses present on their operations on 1 January 1998 were eligible to continue in subsequent phases of data collection with federal and state veterinary medical officers and animal health technicians (USDA, 1999). On three separate seasonal visits, veterinary medical officers and animal health technicians gathered data on lamenesses in horses (USDA, 2000b). The veterinary medical officers and animal health technicians collected fecal and grain samples from operations to test for the presence of *Salmonella* (Traub-Dargatz et al., 2000). Blood-serum specimens were taken from horses on 837 operations to test for antibodies to equine arteritis virus (USDA, 2000a). Considerations for determining the study's overall sample size included not only the available budget and the desired levels of precision of estimates from various stages of data collection, but also workloads that the NASS field enumerators, the federal and state veterinary medical officers and animal health technicians, and laboratories could handle. Moreover, because participation was voluntary on the part of operators, a certain level of refusal had to be anticipated. Since this was the first NAHMS national study to address equids, participation rates were quite unknown at the time that the study was designed.

The precision of population estimates from sample surveys depends on not only the size of the sample, but also the heterogeneity of the population (Sukhatme and Sukhatme, 1970). Once the number of sample units has been established, the objective is then to select a sample in such a way that the variance of population estimates is minimized. Stratified sampling, which consists of dividing the population into strata and drawing one random sample from each stratum, is intended to yield a better cross-section of the population and more precise population estimates than unstratified sampling (Sukhatme and Sukhatme, 1970). In general, the more homogeneous the units within strata, the greater the precision of the resulting population estimates; the more units within a stratum, the larger the sample that should be drawn therefrom; and the greater the variability of units within a stratum, the larger the sample that should be drawn therefrom (Sukhatme and Sukhatme, 1970). If participation rates are expected to vary by stratum, then this should also be taken into account in designing the survey.

Large variation in weights can reduce the precision of survey estimates (Cox and Cohen, 1985). If a few respondents have extremely large weights compared to the majority of the respondents, then the population estimates will be heavily dependent upon responses given by the respondents with the large weights. The weight-smoothing process mitigated the impact of some very large weights. Generally, operations selected from the area frames had larger weights than operations selected from the list frames, and contributed more to the error of estimates.

The analyses of foal mortality were based on data from a subset of Equine 1998 Study participants (i.e. those that had live-foal births during 1997). Although the Equine 1998 Study was not designed specifically to yield estimates of early-postnatal mortality of foals as related to risk factors, the sample size was large enough to yield estimates with an acceptable level of precision.

One limitation of this study is that the data were collected during March and April of 1998, and respondents were asked to recall the number of foals that died within 2 days of live birth during the entire previous year. Thus, some of the respondents might not have been able to recall exactly the age at which their newborn foals died. Respondents with a large number of foals might not have known the exact number of foals that were born or that died. For many operations, births and especially deaths (the maximum number of deaths per operation was four) were rare and sufficiently important events that the recollection of respondents may have been reasonably accurate. The exact age at the death of early post-natal foals may have been more difficult to recall. In any sample survey, a certain amount of non-sampling error is inevitable (Sukhatme and Sukhatme, 1970). Using a questionnaire from a prior NAHMS survey of the dairy industry, Erb et al. (1996) found that respondents gave discrepant answers on about 8.5% of the questions when the questionnaire administration was repeated at a different date. Recollection may be less accurate as the time elapsed from the event and the number of observations increase. Although every effort was made to verify that the data were collected consistently, we cannot know for certain how accurately respondents provided data on age of foals at death and the number of births and deaths per operation. We did not attempt to quantify recall bias by repeated administration of the questionnaire.

Misclassification bias might have occurred if respondents who managed their equids less intensively were more likely to misclassify neonatal deaths as intra-partum (thus rendering them "Acts of God" rather than management errors). Insurance considerations (particularly for more valuable equids) could also have led to misclassification bias.

Another limitation of this study is that no information was collected on how individual mares or foals were managed. Data were gathered at the operation-level, not at the individual animal-level, regarding routine procedures performed on neonatal foals, on where foals were born, and on equine management practices for operations. Therefore, we cannot conclude from this study that a specific management practice caused foal mortality — but rather, that foals born on operations which used a particular practice had a different odds of being reported as dying within the first 2 days of live birth than foals born on operations which did not employ the particular practice. We obviously have a better idea of how an individual foal was handled for the 329 sample respondents who reported the birth of only one live foal during 1997 versus the 714 respondents who reported the birth of more than one foal. However, the operations with fewer equids were generally selected from within the randomly selected geographic areas of the December 1997 NASS Area Survey. These operations were sampled at a much lower proportion, and represented a much larger number of operations in the population than the larger operations that had been selected from lists. The final model indicated that operation size (as measured by the number of resident equids on 1 August 1997) was not a significant predictor.

In general, an analysis which would have ignored intra-operation correlation (and assumed independent responses) would have underestimated the true variance of parameter estimates and led to test statistics with inflated Type-I errors. The use of SUDAAN permitted the computation of estimates and standard errors that took into account both the sample design parameters and the clustering of births on the same operations (Bieler and Williams, 1995).

We made numerous statistical comparisons, and might well have erroneously rejected at least one true null hypothesis (Neter and Wasserman, 1974). Moreover, the ability of the model to predict outcomes for new data may be less than that observed from the data upon which the model was based (Neter and Wasserman, 1974). However, the purpose of this investigation was to find management factors potentially associated with neonatal foal mortality (rather than to construct a predictive model).

No significant differences were reported in the percent of operations by primary use of equids nor by primary function of operation between the southern and western regions (USDA, 1998a). Larger percentages of operations in both the southern and western regions used equids primarily for farm or ranch work than in other regions of the country (USDA, 1998a). However, the US equine industry is certainly very heterogeneous within the regions defined for this analysis. The southern region included Florida (where over one-half of the horses were used in showing) and Kentucky (where the majority of the people involved in the horse industry participated in racing) (American Horse Council Foundation, 1996). The NAHMS Equine 1998 Study was not designed to provide state-level estimates. The higher mortality risk shown for the southern region (compared to the western region) may have been due in part to the recall bias described above. If a foal is very important to the economic well-being of an owner/operator, the owner/operator may have a better capacity to remember (or better records — such as computerized records — to indicate) the age at which foals died. Such operators may also have a higher level of observation at foaling, and different criteria for culling foals. Climatic differences could have had an impact on differences in foal mortality: the southern region is generally warmer and more humid than the western states.

Cohen (1994) reported that the practice of assessing passive immunity was significantly associated with decreased incidence of septicemia and pneumonia in foals. Routinely testing newborn foals for adequate absorption of colostral immunoglobulins may indicate a high level of care of early post-natal foals. Although no other variables related specifically to the care of foals within the first 2 days of life passed the variable screening, most respondents who indicated the routine testing of foals for adequate absorption of colostral immunoglobulins during the first 2 days of life also typically had the foals examined by a veterinarian, dipped the navels with antiseptic, and gave the foals an enema during the same time frame. Associations between these variables and neonatal foal mortality were weak ($P \geq 0.25$). The perceived value of a newborn foal varies considerably depending on the intended use, the breed, and bloodline within breed. Usual costs to produce a new foal include the stud fee, housing and transportation to the breeding facility (unless the semen is shipped), monitoring the mare for foaling, veterinary and other care of the mare and foal, etc. The results of this analysis suggest that even if one only considers the cost of the test for adequate absorption of colostral immunoglobulins and the hypothetical value of a foal, one has a lower expected cost when one tests the foal for adequate absorption of colostral immunoglobulins except where the hypothetical value of the foal is $<\sim$US$ 1000. If a veterinarian is present within 2 days of a live birth and evaluates the foal for adequate absorption of colostral immunoglobulins, it is likely that the veterinarian is able to examine the foal and intervene for other health problems as well. Early diagnosis of inadequate absorption of colostral immunoglobulins can lead to interventions that may prevent mortality in foals during the early post-natal period (McGuire et al., 1977). In the NAHMS Equine 1998 Study, no data were collected on the number of foals with inadequate absorption of colostral immunoglobulins, nor on interventions for foals with failure of passive transfer on study farms.

Biosecurity practices are important to reduce the risk of cause-specific morbidity and mortality due to infectious diseases (Doherr et al., 1998). Contact with other animals can result in the spread of infectious agents which cause disease (Doherr et al., 1998). While introducing equids from outside the operation (both as permanent acquisitions and as temporary visitors) was associated with increased foal mortality within 2 days of a live birth, no information was collected on whether the foals born on an operation were born to resident mares or visiting mares, nor on whether visiting non-resident equids were broodmares. The health risk to foals born to visiting mares and to resident mares is potentially different. Traub-Dargatz et al. (1988) reported that foals born to visiting mares were more likely to develop diarrhea than foals born to resident mares. The practice of requiring a health certificate for non-resident equids that visited for <30 days may either reduce the risk of disease exposure to foals, or reflect a higher level of equine health care on the operation.

In the present study, information was collected on the types of bedding used for equids during 1997, and on the predominant bedding used. However, no questions were asked specifically on the bedding used for newborn foals. Most respondents who did not use straw or hay as the predominant type of bedding for equids on the operation indicated that wood shaving, chips or sawdust was the predominant bedding used. Traub-Dargatz et al. (1988) found that the use of wood shavings in foaling stalls was associated with a higher occurrence of foal diarrhea. Further research is needed to determine whether pathogens that cause diarrhea in foals are less prevalent in straw or hay bedding than in other types of bedding, or whether the type of bedding is a marker for some other associated management risk factor.

No information was collected on the type of vitamin-mineral supplements fed to equids nor on the reasons for feeding it. It is possible that this variable entered the model purely by chance, because the result was contrary to what one might have anticipated. Some respondents may have fed the vitamin-mineral supplement premix as a remedy to a perceived equine-health problem. Further research is required to determine the possibility that some of the respondents who fed a vitamin-mineral supplement premix to equids may have fed too much, resulting in altered viability of newborn foals. We do not know whether the vitamin-mineral supplement premix was fed to broodmares or just to other equids; respondents reported feeding the supplement if it was fed to one or more equids on the operation during 1997 (USDA, 1998b). Equine owners should pay particular attention to the nutritional requirements of pregnant mares in determining the need for supplementation of pregnant mares with vitamin and mineral supplements.

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